White Paper on

"Electron Radiation Belt Modeling using Data Assimilation Methods and Los Alamos Geosynchronous and GPS energetic particle data"

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Introduction

The natural energetic electron environment in the Earth's radiation belts is of general importance as it can impact space hardware in those regions and contribute significantly to background signals in a range of other instruments flown in that region. To this end particle detectors have routinely been flow on a range of DOE spacecraft in geosynchronous and GPS orbits.

Data from any single point measurement in space to date has only been used to derive information about the local environment at that satellite. We present here a synthesis between multiple point space measurements and a physics based radiation belt model that makes full use of all the data from our current constellation of energetic electron measurements in space (up to 6 simultaneous geosynchronous and 4 simultaneous GPS orbit measurements) and uses the model to provide a physical interpolation between the data. The end result is a dynamic and global model of the energetic electron radiation environment at all points in space, which can provide reliable environmental data for locations of satellites that *do not* carry any energetic particle instrumentation.

The Model

We use here a custom version of the SALAMMBO radiation belt code developed by our collaborators at ONERA in Toulouse, France. This is a diffusion code that models all physical processes in the inner magnetosphere by their respective diffusion coefficients (radial and pitch angle diffusion). This code used the Planetary disturbance index Kp to parameterize radial diffusion and the position of the plasmapause which controls wave activity and thus pitch angle diffusion. The code is symmetrical in local time since on a given drift orbit particle fluxes are the same at all local times on timescales on the order of the drift time, which is typically around 10 minutes for the highly energetic electrons. The code traces the full particle distribution function in the coordinate space of L* (magnetic coordinate of the drift shell), B/Bo (the ratio of the local magnetic field strength to the equatorial magnetic field strength on a given magnetic field line) pitch angle and energy.

Data assimilation technique

This model has been tightly integrated into our data system at LANL, and allows us to input data from various spacecraft sources directly into the model grid. The difference here is that the model no longer uses a simple boundary condition, but allows direct input into the code grid at any location for which data is available. This corresponds to the data assimilation method of "nudging". In order to seed the code with real data the data has to be transformed into the model coordinate space. Due to the nature and limitations of the data used this requires some assumptions. Current data sources only provide omni-directional data and no magnetic field information. We thus employ a strategy that uses model magnetic field information and statistically derived "most likely" pitch angle distributions. In addition, whenever there are "conjunctions" in the input data (satellites at the same L* but at different magnetic latitudes) then we can use a fitting procedure to derive the best fit to a pitch angle distribution.
In a general run input data thus transformed is entered into the grid for the locations and times available, and the model diffusion action is allowed to act for all other periods and areas.

Model/Data assimilation output

Once a model run for a given set of input data for a given period has been performed, we can "fly" any required spacecraft orbit through the model grid. All we need to do is to transform any satellite ephemeris to the required magnetic coordinates of the model grid.

Inter-calibration issues

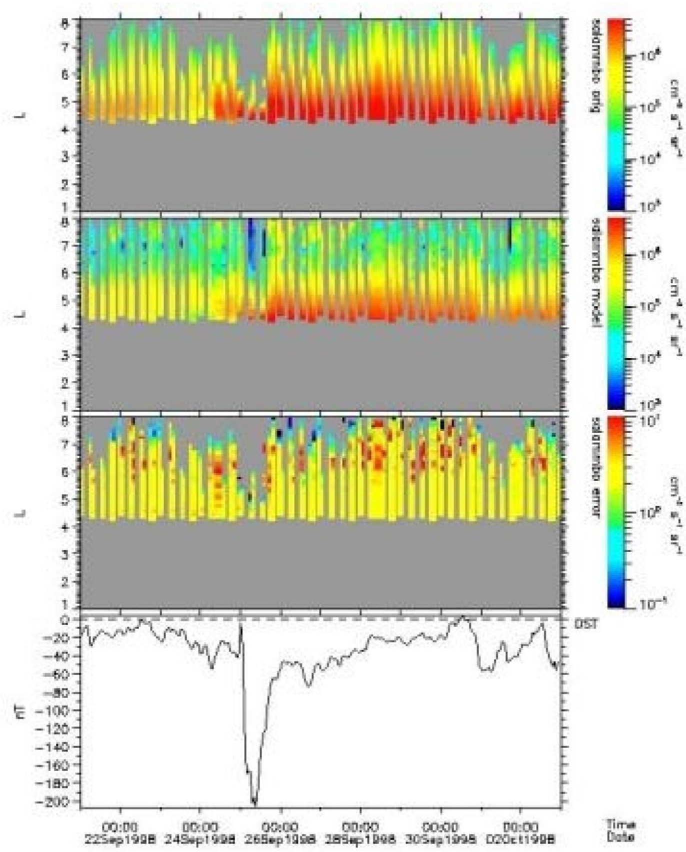
In order to seed the model with data from various platforms/instruments they need to be inter-calibrated to some high degree of fidelity. This is a notoriously difficult task for energetic electron instruments. A major effort has been undertaken to cross calibrate and ground truth data from all LANL GEO and LANL GPS instruments. The data has been referenced to CRRES measurements in 1990/1991 and then propagated forward and backward in time to cover the full time period of the data to the present. Any new data added to the system needs to undergo a similar procedure. For the current data we are confident to have the inter-calibration right to within a factor of 2.

Magnetic field issues

As is evident from the discussion above knowledge of the magnetic field and the full particle pitch angle distribution is required, as this is critical for the mapping into and out of the model grid. For the geosynchronous data we can use the physical symmetries of the particle distribution and the high-resolution directional information to determine the magnetic field direction and thus the pitch angle distribution. An effort to do this in underway. Once the pitch-angle resolved data becomes available we intend to use the multi-spacecraft data at geosynchronous orbit itself to help define the "real" global field in the geosynchronous region, by modifying model magnetic fields until the drift orbits derived from them fit all the data taken. Then we can not only seed the Salammbo code with real data but also use real data to define the mapping into the code grid. A postdoc project on this topic will start in August 03.

First results

An initial run was performed for one the period of one of the NSF GEM storm of September 1 - October 10, 1998. Inputs used were one geosynchronous satellite (LANL-GEO 1994_084) and one GPS satellite (ns33). The same ns33 satellite was then flown through the model and compared.



The top panel shows the actual satellite data for the >0.28 MeV channel on ns33. The next panel shows the model output along the orbit on ns33, and the third panel shows the ratio between data and model. Ideally this ratio should be 1 (green), here it is consistently yellow, which means within a factor of two. This reflect the current uncertainties in the input data inter-calibrations and the mapping round-off errors into and out of the current model grid. Important is the consistency throughout the active period.

Other model runs using a different satellite as "output" shows the same factors of 2-3 between measured and predicted values. More importantly, these ratio go up to around 10 or more if GPS ns33 data is not used.

This project is in its initial stages and a lot of further fine tuning of the assimilation method and input data is needed. First results however are promising. We anticipate using this model/data synthesis both for research and for Space Weather now-casting (limited by real-time data availability, currently not possible for GPS). For research, having this model "specify" the real environment we can then run the model in a not assimilative mode to see what physics is missing/under-represented. For Space Weather, we can specify the environment for any past time time going back approximately one solar cycle, which is required for any post-event anomaly analysis.

Further, we can use this model to explore exactly what kinds of data and data locations are needed for optimal input that would increase the fidelity of the model.

<u>End Report.</u>